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1. SCOPE

This document provides the design description of the AMS cryocoolers Thermal Control System (TCS), including the support beams which serve to carry the TCS components and other sub-systems elements (different from the TCS).

This document corresponds to contract deliverable DEL 077.

2. APPLICABLE AND REFERENCE DOCUMENTS

Documents here below identified are applicable and/or reference for the activities described in the present document and are considered part of it to the extent specified herein.

2.1 APPLICABLE DOCUMENTS

<u>CONTRACTUAL</u>

AD1 Capitolato generale ASI, available on http://www.asi.it/html/norme/cap_gen.pdf

AD2 Richiesta d'offerta per Programma AMS, attività di Fase C/D – Prot. ASI 006194 – 25/07/2007

AD2bis CapitolatoTecnico "Progetto: AMS Attività di fase C/D" Doc. N. DC-IPC-2007-062

AD3 Tailoring di primo livello delle norme ECSS, serie M-E-Q – Progetto AMS attività di fase C/D- Doc. n° DC-IPC-2007-063 Rev. A

<u>MANAGEMENT</u>

AD4 "ECSS Glossary" – Doc. ECSS-P-001 Rev. B

<u>PRODUCT ASSURANCE</u>

AD5 "Product Assurance Requirements - Progetto AMS attività di fase C/D "-Doc. n° DC-IPC-2007-064 Rev. A

AD6 "Istruzione Operativa "Norme per la redazione del Piano di Assicurazione del Prodotto (PA Plan)", Doc. OP-IPC-2005-008

AD7 "Sistemi di Gestione per la Qualità", doc. UNI EN ISO 9001:2000

AD8 "Quality Management Plan for the Alpha Magnetic Spectrometer 02 (AMS-02) Experiment", Doc. JSC63164, Basic Version, 09/21/2005

AD9 "Master Verification Plan (MVP)", Doc. JSC 29788, Iss. Draft, 8/21/2006

AD10 "PA REQUIREMENTS DC-IPC-2007-064 RevA Conformity",doc AMSCD-RQ-CGS-001 issue 1

<u>ENGINEERING AND TECHNICAL</u>

AD11 "Multi-Layer Insulation for the Alpha Magnetic Spectrometer Guidelines", Doc. CTSD-SH-1782, 9/30/2005

AD12 "AMS-02 Structural Verification Plan for the Space Transportation System and the International Space Station", Doc. JSC28792, Iss.D, March 2005

AD13 "Experiment/Payload Integration Hardware Interfaces - Part I", Doc. JSC29095, Iss.A, 06/01/2002

AD14 "Experiment/Payload Integration Hardware Interfaces - Part II", Doc. JSC29095, Iss.A, August 2004

AD15 "Experiment/Vacuum Case Payload Integration Hardware Interface", Doc. JSC29202, Iss.C, March 2005

AD16 "AMS-02 thermal requirements specification document ", Doc AMSTCS-SP-CGS-003, Iss 1, 25/03/2008

AD17 "Attached Payload Interface Requirements Document , Doc. SSP 57003, Iss B, 17/06/03

AD18 "Attached Payload Hardware Interface Control Document, Doc. SSP 57004, Iss. B, 13/06/03

AD19 "AMSPDS-RP-CGS-001", Doc. PDS Design Description, Iss.2, July 05

AD20 "AmsE-PPL", AMS Electronics Preferred Parts List, available on (http://ams.cern.ch/AMS/Electronics/Parts/), Iss.1, Nov 01 configured on doc PDS-LI-CGS-006 iss 1

AD21 "PDS ICD - Interface Control Document", Doc. AMSPDS-IC-CGS-001, Iss.3, July 05

AD22 "PDS Specifications", Doc. AMS-RQ-CGS-002, Iss.1, April 07

2.2 REFERENCE DOCUMENTS

[RD 1] Phase II Flight Safety Data Package for the Alpha Magnetic Spectrometer - 02 (AMS-02) Version Basic JSC49978 , 2006

[RD 2] Alpha Magnetic Spectrometer – 02 Assembly and Testing Integration Plan, Version A, JSC63123, 28-11-2005

[RD 3] Dichiarazione INFN sulla consegna di componenti – lettera del 20 maggio 2007 (prot. ASI n. 0009869)

[RD 4] *Capitolato gestionale ASI OP-IPC-2005-010-E*

[RD 5] AMSTCS-TN-CGS-012, *Cryo TCS thermal analysis report*, 31/03/2007, issue 1

[RD 6] AMSTCS-IC-CGS-002, *Cryo TCS ICD*, 31/03/2007, issue 1

[RD 7] AMS-552-PROC-041, *Alpha Magnetic Spectrometer – 02 (AMS – 02) LHP Integration with Cooler Bracket Assembly*, rev. - , 26 March 2007 (by NASA/GSFC)

[RD 8] AMSTCS-TN-CGS-014, *AMS02 MLI description report*, 31/03/2007, issue 1

[RD 9] 40-AMS02TCS-220.00.00, ZENITH RADIATOR PANEL ASSY

[RD 10] 40-AMS02TCS-220.01.00, ZENITH RADIATOR PANEL ASSY PART LIST

3. CRYO TCS THERMAL CONTROL SYSTEM

3.1 OVERVIEW AND COMPONENTS IDENTIFICATION

The heat dissipated by the cryocoolers is collected by a Loop Heat Pipes system, and rejected to space by a dedicated radiator. In this paragraph the main TCS components and their general layout is presented, further details are provided into each of the following sections.

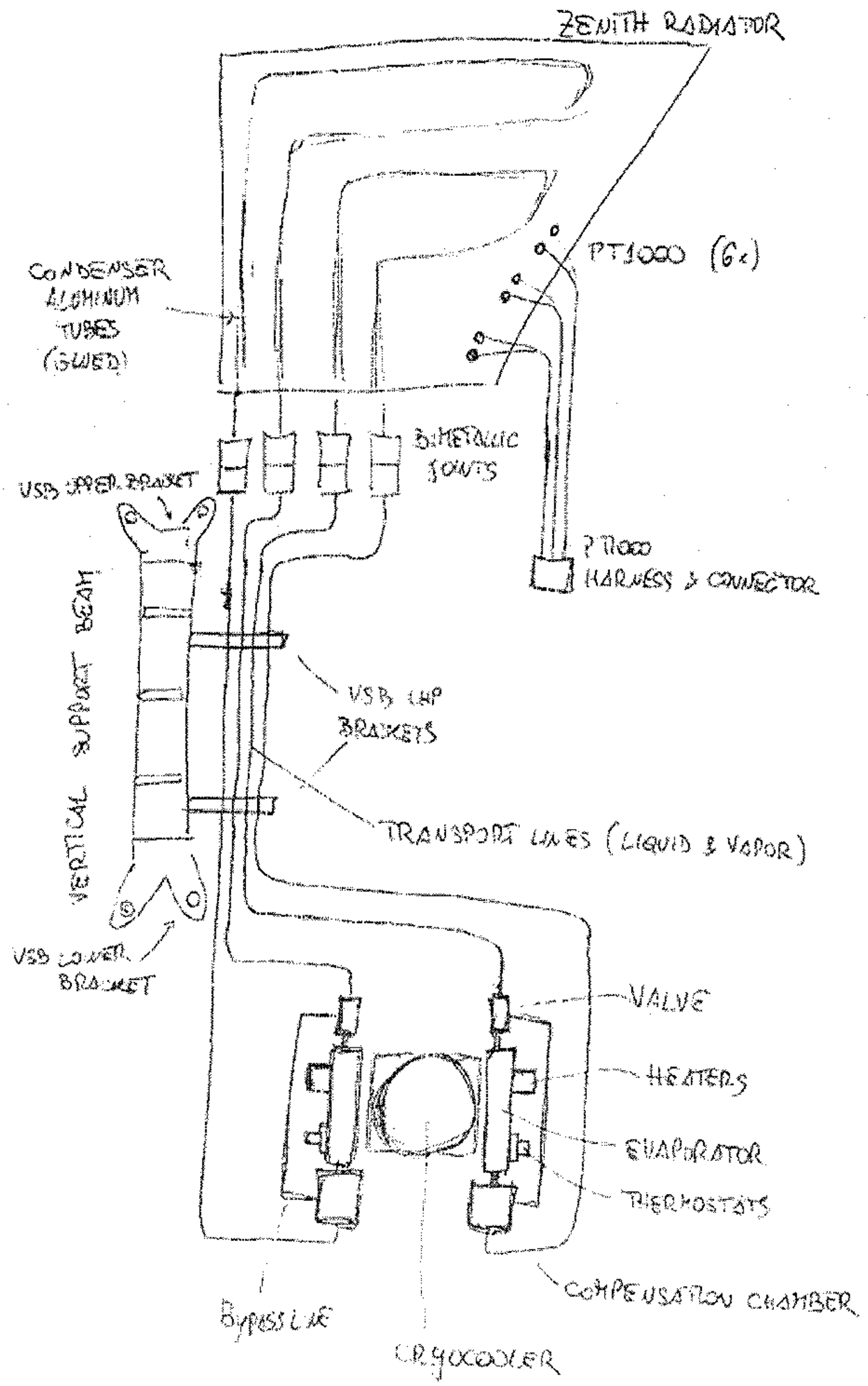


Fig 3-1 Schematics of the TCS for a lower vacuum case ring cryocooler (upper VC ring cryo's don't have the VSB)

4 cryocoolers are mounted onboard of the AMS-02 experiment, two on the upper ring of the magnet vacuum case (opposed to each other) and two on the lower ring, rotated by 90° with respect to the upper ones. Cryocoolers are designed, built and integrated under the responsibility of NASA – GSFC.

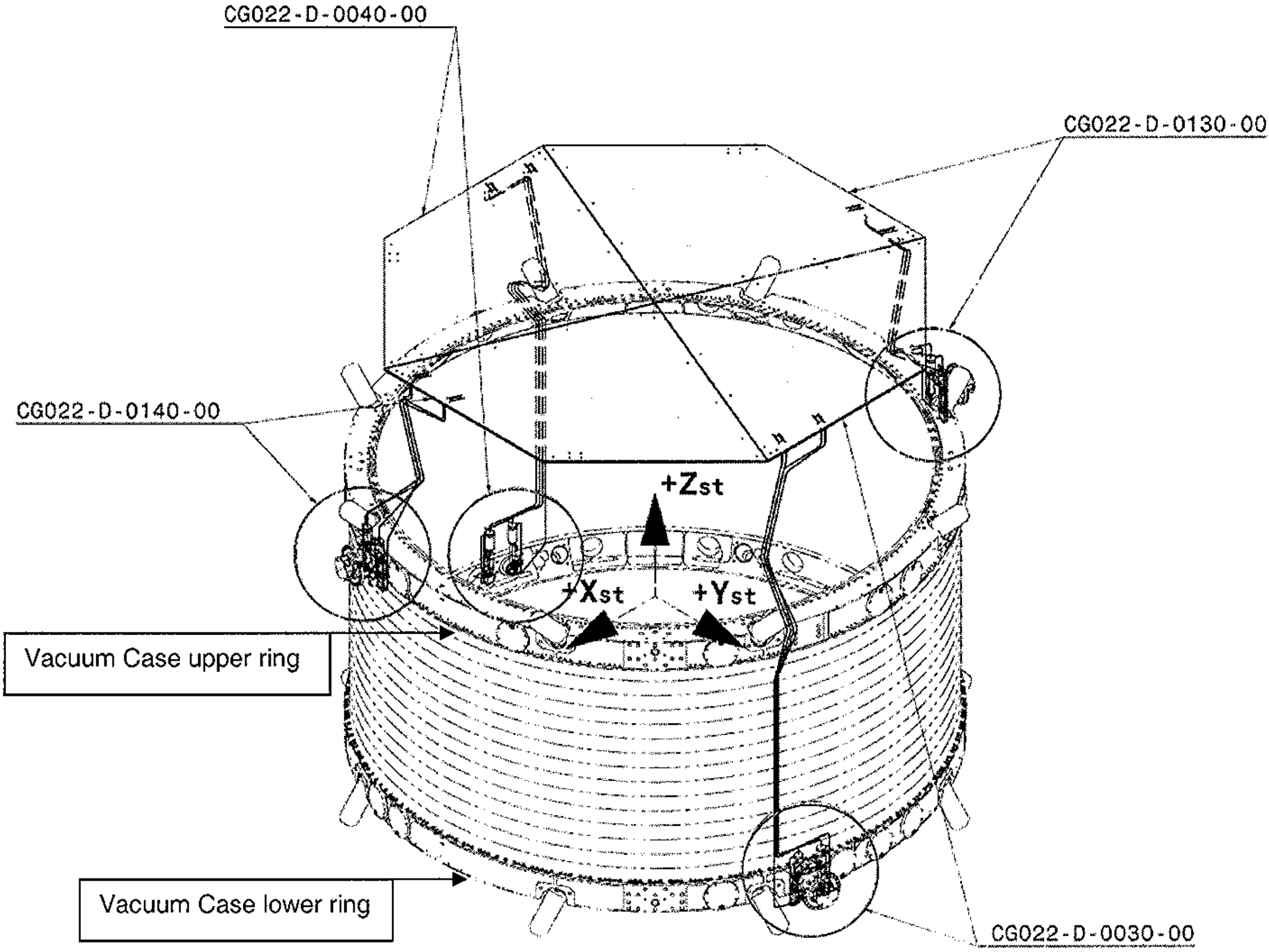


Fig. 3-2: Cryocoolers location on AMS-02 vacuum case rings (highlighted in red)

Each cryocooler, whose task is to drain thermal power from the low temperature outer thermal shield of the Vacuum Case, dissipated a variable amount of power, as specified in AD16. This power (in the range 63 to 158W) has to be carried to a dedicated radiator which is located on the top of the AMS-02 experiment, above the TRD.

Modular design lead to the definition of a independent TCS per each cryo, with an independent radiator. Therefore, the radiator system on top of AMS-02 is composed of 4 identical radiator slices, one per each cryocooler, each one with the shape of ¼ of an octagon. These radiators are referred also as "Zenith radiators".

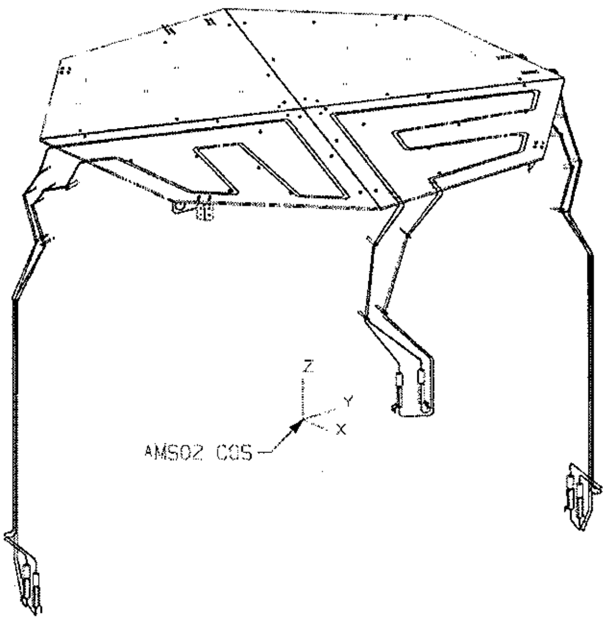


Fig. 3-3: Zenith radiator slices. Each slice hosts the condenser lines of the two LHP of each cryocooler

The way the heat is transferred from the cryocooler to its radiator is through a pair of Loop Heat Pipes (LHP). LHP are among the most efficient ways to transfer large amounts of heat at distant points; the heat to be rejected causes the evaporation of a working fluid inside a porous wick (made of nickel) on the evaporator component. The fluid is pushed by capillary forces through a fluidic loop towards a condensing zone (the radiator). After the fluid has condensed, the liquid is conveyed back to the evaporator, passing through the compensation chamber (whose task is to regulate the loop performance under different environmental conditions). The working fluid selected for the AMS-02 Cryocoolers TCS is propylene, the decision lead in particular by the necessity to avoid fluid freezing. To prevent the LHP from bringing the cryocooler temperature below its operational range, a temperature passively-actuated valve (located on the vapour line) is able to redirect the vapours to the Compensation Chamber, thus bypassing the condenser zone and keeping the cryocooler warm.

In total there are 8 LHP systems, two per cryocoolers. Each pair of LHP which is connected to the same cryocooler is then condensing on the same radiator.

The fluidic transport lines (both the vapour line coming from the evaporator and the liquid line redirecting the fluid to the compensation chamber of the LHP) are made of steel, like the compensation chamber and the jacket of the evaporator Scientific goals requirements, however, prevented the use of steel tubes on the radiator, due to the interaction with high energy particles. Only aluminium tubes are allowed to run on top of the experiment

Therefore, in proximity of the radiator, there is a transition from the steel transport lines to the aluminium condensing section. This transition is mediated by a bimetallic joint, which is welded on both sides to the tubes. There are 4 bimetallic joins per radiator slice, 16 in total.

The transport lines, as well as the entire cryocooler body protruding from the Vacuum Case, are protected from the environment by means of Multi Layer Insulation (MLI). This allows in particular to consider adiabatic the LHP system until it reaches the radiator.

The LHP are also equipped with startup heaters and related thermostats in order to allow the controlled start of the loop circulation. Heaters are places on each evaporator body, on a dedicated fin; each fin hosts a main and a redundant line, and each line is protected by a thermostat.

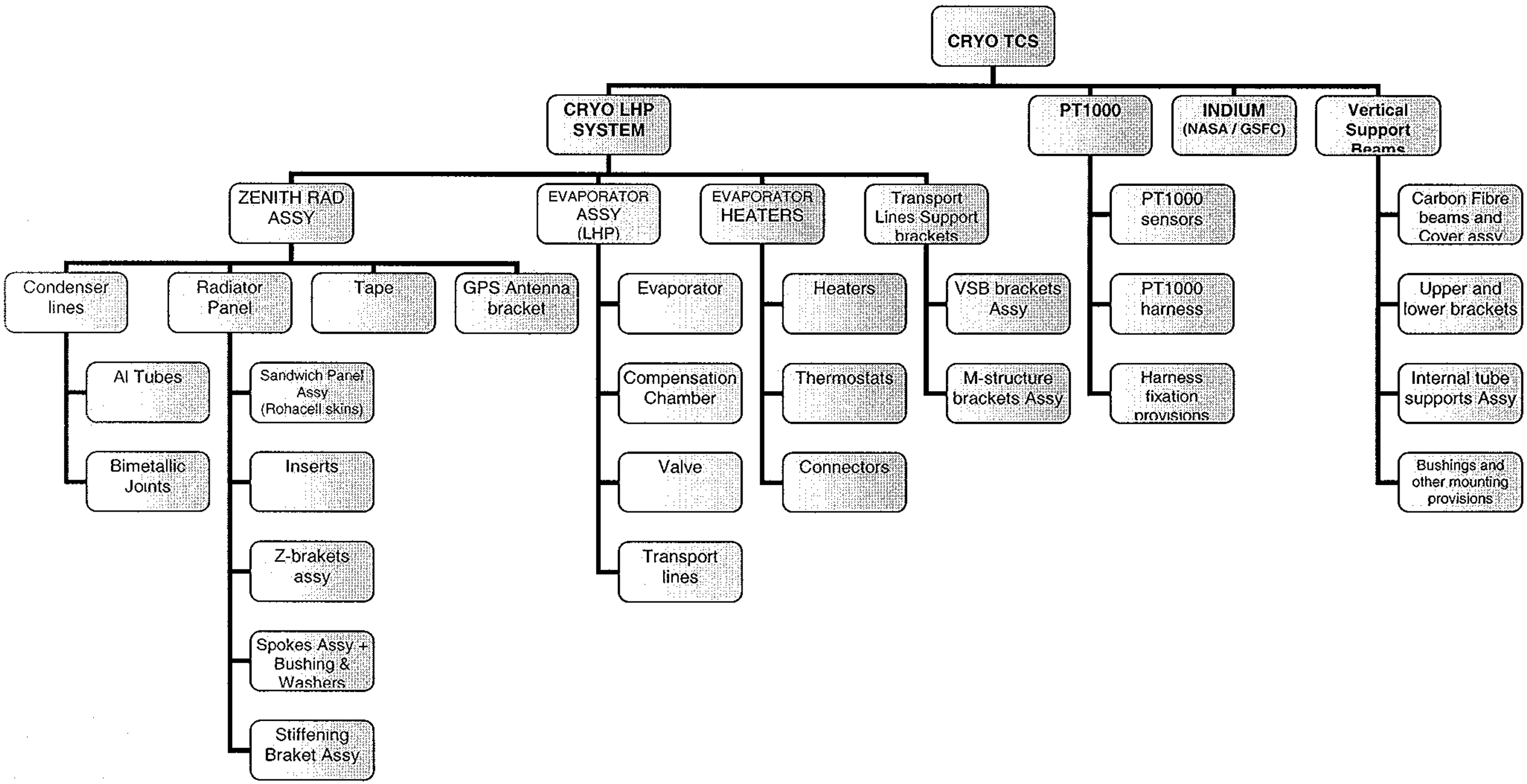


Fig. 3-4: TCS main elements list

3.2 LHP

The LHP elements drawings, up to the condensing section excluded (radiator and bimetallic joints) are reported in Annex A.

8 different LHP assemblies are provided, 2 per cryocooler. Some elements are common to all of them (evaporator, valve, bypass line) while the transport lines length and routing, and consequently the compensation chamber size, is different from case to case. The working fluid is propylene, which does not suffer from freezing hazards being its freezing temperature (-186°C) much lower than the minimum expected LHP temperature in the worst case analysis (larger than -130°C, see Thermal Analysis report [RD 5] for details).

Each LHP is composed by the following elements:

3.2.1 EVAPORATOR

The evaporator is composed of a primary wick (diameter 14mm) made of sintered nickel powder.
The wick is 100mm long, and hosts 4 axial grooves.
The wick is encapsulated into a 0.5mm thick steel jacket.
The steel jacket is on its turn brazed into an aluminum saddle, which provides the interface to the cryocooler heat reject collar. The shape of the saddle is optimized to fit into the strict available room at the cryocooler interface
The saddle (see also the interface control document [RD6]) is bolted with 14 bolts onto the cryocooler interface, and the interface conductance is enhanced by an Indium foil supplied by the cryocooler group (NASA-GSFC).

The bolts torque and the interface management is reported in RD7 (NASA-GSFC LHP installation procedure)

The evaporator saddle hosts a fin (26x27mm2, available flat surface is 26x26 mm2) to allow the mounting of the startup heaters.

3.2.2 COMPENSATION CHAMBER

The compensation chamber (CC), mounted above the evaporator, is different per each cryocooler, being different the fluid inventory because of the different lines length. The CC is made of steel. It receives the liquid line returning from the condenser, and the bypass line from the valve. The fluid is then conveyed towards the evaporator (no secondary wick is present)

The CC has an outer diameter of 40mm, and a variable length according to the fluid inventory

3.2.3 BYPASS VALVE

The bypass valve has the task to redirect the vapor back to the compensation chamber whenever the vapor temperature is higher than a defined setpoint. It is divided into two compartments, separated by a bellow.

The working principle is the differential pressure generated by the propylene on one side, and on an Argon reservoir on the other side of the bellow. This differential pressure (which is driven by absolute temperature values of the system) serves to move the valve stem and open or close the circuit branches.

The valve is characterized by a transition temperature range, from the fully open position (all the vaport in the radiator/condenser branch) to the fully closed position (all the vapor to the bypass line, towards the CC). The Argon back pressure, which regulated the set point, is such that the fully closed position is reached at -20°C.

This corresponds to an actuation range from -8°C (begin of actuation) to -20°C (fully closed valve).

3.2.4 TRANSPORT LINES

Transport lines serve to bring vapor to the radiator and to return the condensed liquid. Transport lines shape and length is different per each single LHP.

Common to all the lines are the material (stainless steel) and diameters: vapor lines are 3mm ID, 4mm OD. Liquid lines are 2mm ID, 3mm OD.

3.3 BIMETALLIC JOINTS

To allow the welding between the aluminum alloy cryocooler condenser tubes (embedded into the Zenith radiator panel) and the inlet and outlet stainless steel external condenser tubes, a set of bimetallic joints are needed.
Bimetallic joint is small cylindrical joint made of two different materials (Stainless Steel AISI 316 and Aluminum alloy 6061-T6) welded together by means of a particular welding technology, called "explosion welding" developed by Atlas (US). Joints shall be machined from a standard welded plate.
Aluminium and stainless, are not directly bondable without the formation of brittle intermetallic compounds. Due to this, Atlas has developed patented multi-layer composites technologies that provide metallurgical compatibility to aluminum and stainless as well as other metals.
Multi-layer composites also provide diffusion barriers eliminating the possibility of the formation of the brittle intermetallic compounds during weld up or through repeated heat cycles such as bake out and high heat processes.
Titanium and copper are the typical materials used for to achieve diffusion protection for aluminum/stainless flanges. All materials used are UHV compatible and are metallurgically bonded, no adhesives are used.
In the following figure, a bimetallic joint plus the un-welded condenser tubes is shown.

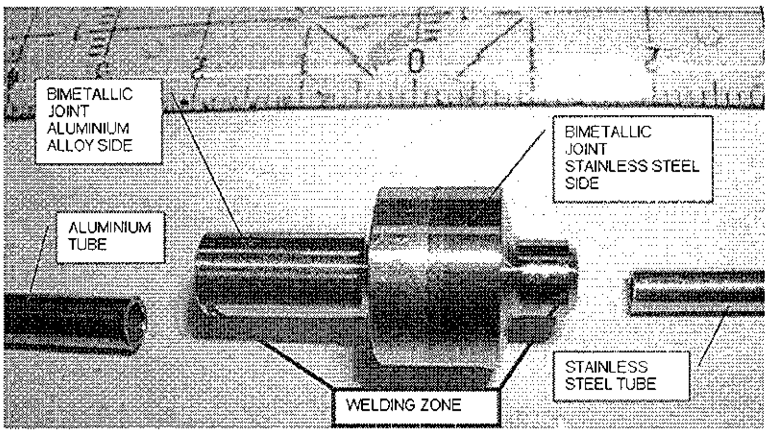


Fig. 3-5: Bimetallic Joint

Four bimetallic joint are foresee for each zenith radiator assy (two for the inlet and two for the outlet condenser tubes). Two structural brackets supply a rigid connection between the Zenith radiator panel and the Cryo cooler loop heat pipe tubes as detailed in the following Figure.

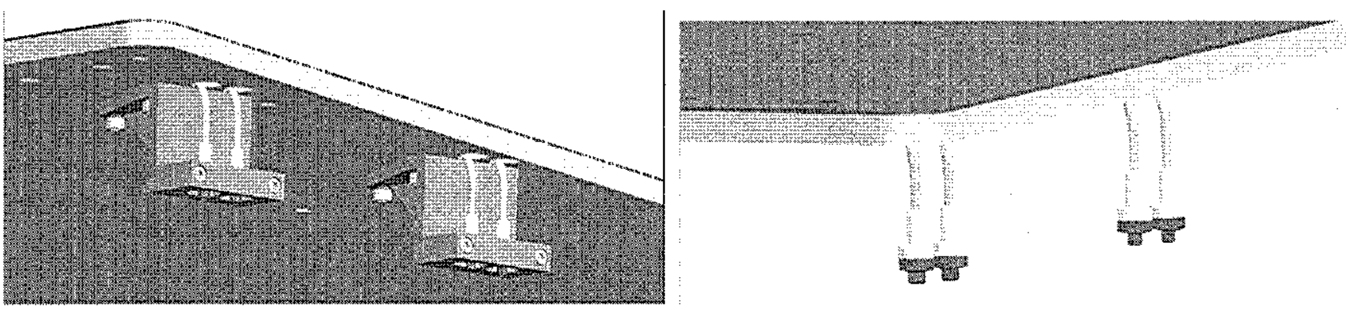


Fig 3-6: bimetallic joint with and without support brackets

3.4 HEATERS AND THERMOSTATS

Startup heaters are foreseen on the evaporators, in order to allow proper startup of the LHP whenever needed. Two lines are available, A and B. Lines are independent. Each evaporator has two heater circuits (fed by A and B respectively), and each line has a thermostat to prevent overheating of the evaporator

The heaters features are reported below:

Heater nominal supply voltage: 120 VDC
Heater Maximum supply voltage on ISS: 126.5 VDC
Heater Minimum supply voltage on ISS: 113 VDC

Maximum heater power density when film heaters are glued onto a metallic plate: 3W per square inch (0.465 W/cm2) → to be calculated at maximum voltage
Maximum heater power density is not applicable whenever the heaters are mounted with additional mechanical support (e.g., bolted counter brackets)

The amount of the startup heaters is not defined yet, and can be evaluated only with test on the manufactured LHP system. The available fin on the evaporator body allows for 6.3W maximum (heater on both fin sides) at maximum voltage, which corresponds to 5.0W at 113VDC.

According to the test results, appropriate heater design and retention methods shall be applied. Heaters shall be (kapton foil / metal wire) and (single / double sided) heaters according to the power density requirements.

The circuit schematic is as follows:

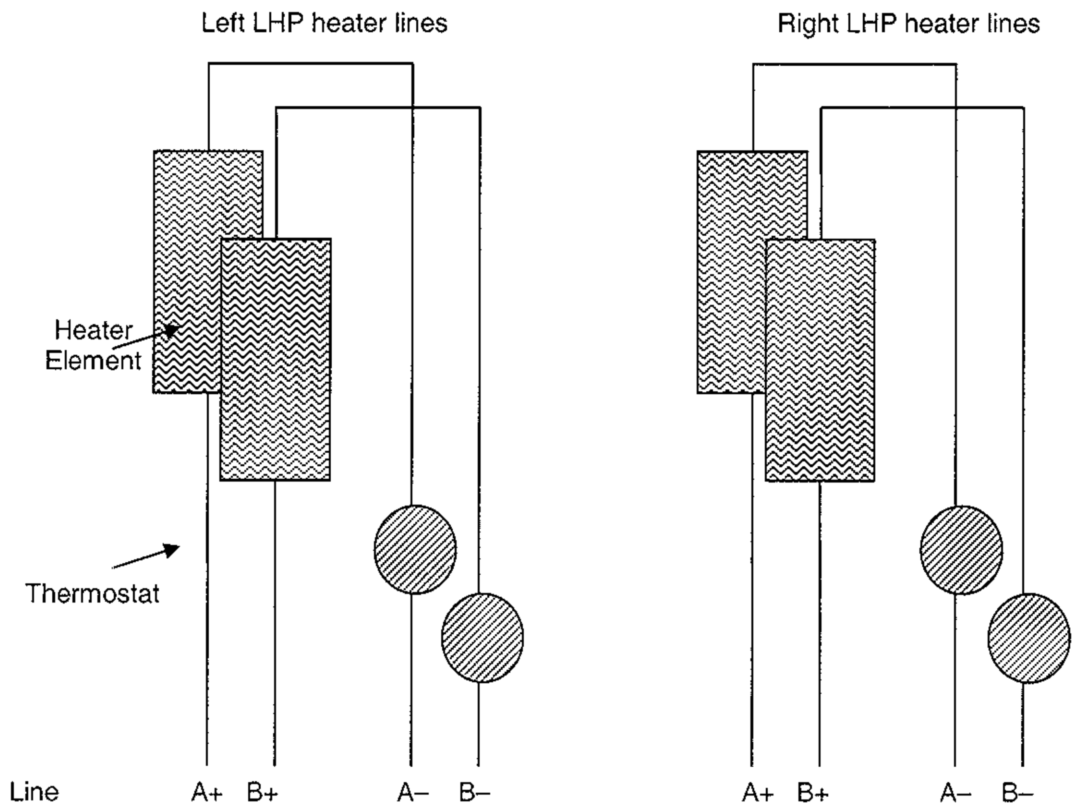
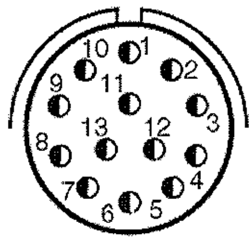


Fig 3-7: Heater schematics for the 2 LHP of each cryocooler

The 8 heater wires labeled A/B +/– in the figure above shall be redirected to a circular connector on the cryocooler bracket. All wires shall be AWG22. The cryocooler bracket (provided by NASA/GSFC) will host a connector type MS27508E10F35PA, 13contacts for AWG 22D, pin (male connector), shell size 10.

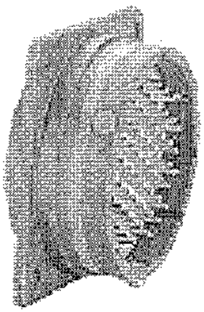


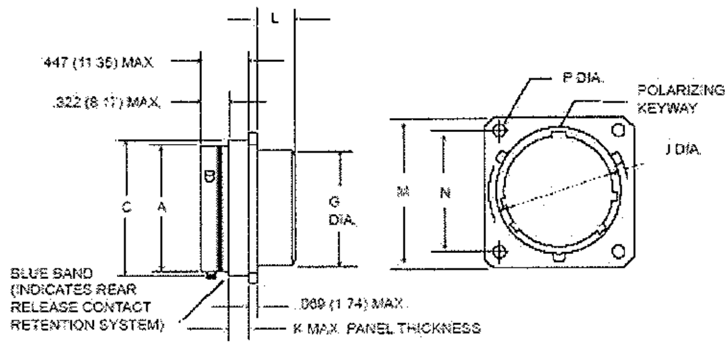
MIL-C-38999 Series II Connectors KJ

Box Mounting Receptacle (Back Panel)

MS27508E
(MS service class E)

KJ5E





NOTE: This connector does not accommodate backshells

Shell Size	A Dia. Max.	C Dia. Max	G Dia. Max.	J Dia. Max.	K Max.	L Max.	M Max.	N T.P.	P +.005 (0.13) -.010 (0.25)
8	.474 (12.04)	.522 (13.26)	.421 (10.69)	.583 (14.80)	.147 (3.73)	.185 (4.70)	.826 (21.03)	.594 (15.09)	.125 (3.18)
10	.591 (15.01)	.639 (16.23)	.542 (13.77)	.680 (17.27)	.152 (3.86)	.185 (4.70)	.954 (24.23)	.719 (18.26)	.125 (3.18)

Fig. 3-8: Heaters circular connector dimension and pins

More information on the connector and electrical interfaces in general is provided in [RD 6]

The set point of the thermostats is +40°C. This prevents overheating of the cryocooler evaporators area above its maximum temperature, while leaving the possibility to start-up the heaters even at high environmental and high cryocooler temperatures.

Thermostat are Open on Rise type, with opening/closing temperature range +34°C÷+40°C, case type 701 (no flanges) and Honeywell part number is G311P641/03701S093A104/3/3/5.

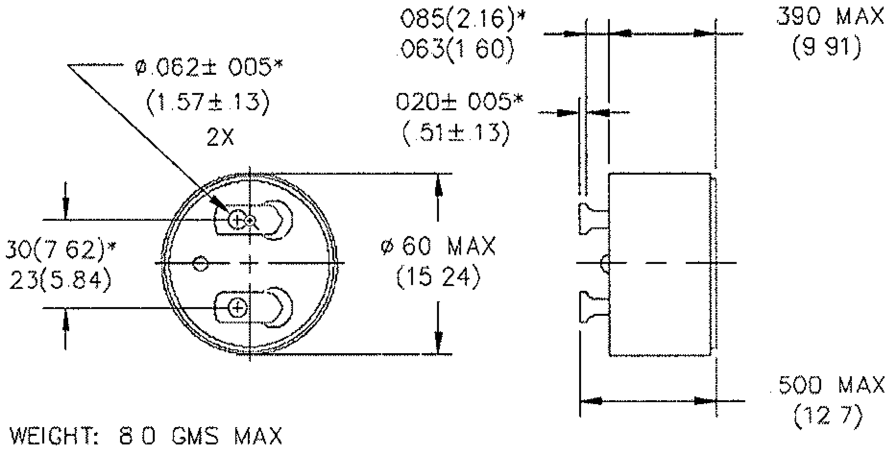


Fig. 3-9: Thermostat dimensions

3.5 MLI

MLI blankets shall cover the cryocooler area, preventing heat leakage and direct illumination on the crayon body and on the evaporator block.

MLI shall also isolate the transport lines in order to limit the heat exchange with the environment.

Details on the MLI blankets (layers, grounding) are given in [RD8]

3.6 ZENITH RADIATOR

3.6.1 PANEL

The Zenith radiator panel consists of sandwich structure with Rohacell core, two aluminium face skins, embedded condenser tube plus bimetallic joint and inserts.
All the parts shall be cold glued together using paste adhesive, under vacuum bag.
In the following Fig 3-10 radiator overviews is shown, while all the technical engineering data are collected in Table 2.5 1.5
The detailed design information is available in the Zenith Radiator Engineering Drawings and Part List in [RD 9] and [RD 10].

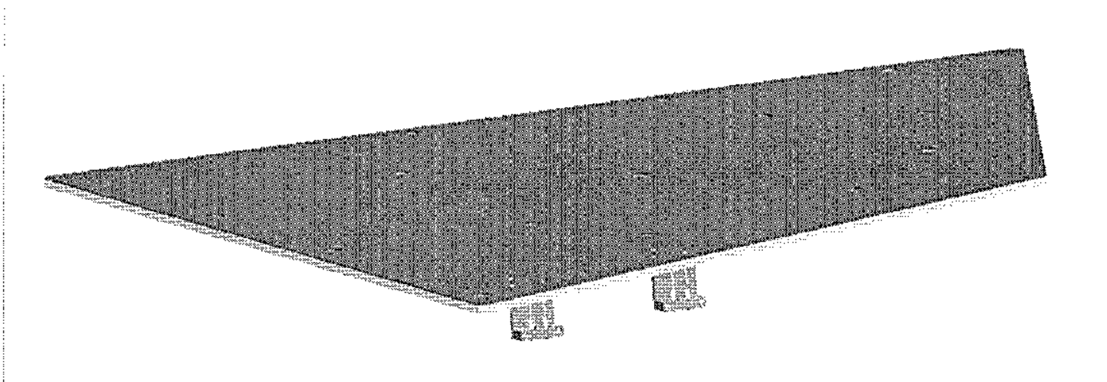


Fig. 3-10: Zenith radiator assembly view

The passive thermal control system is realized by means of two condenser tube lines, cold glued on the outer skin as detailed in Fig. 3-11.
Tubes are in aluminium alloy 3103 0 with OD 4mm and ID 3mm

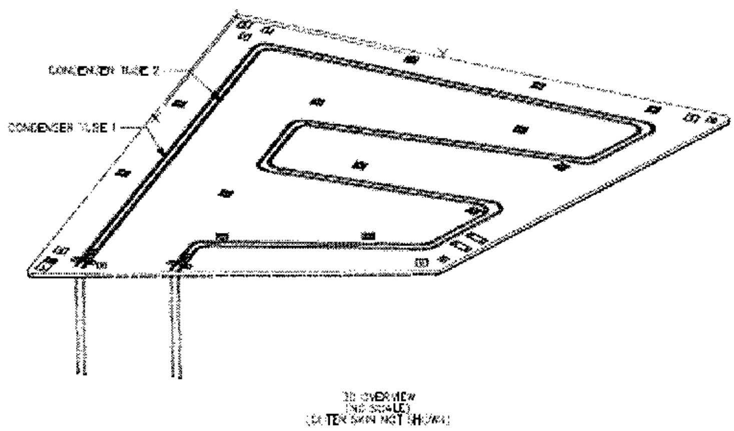


Fig. 3-11: LHP condenser layout on zenith radiator

A set of inserts, positioned between outer and inner skins, supply a structural fitting interface point with spokes and brackets
Typical panel cross sections, with installed inserts, are shown in the next Figure

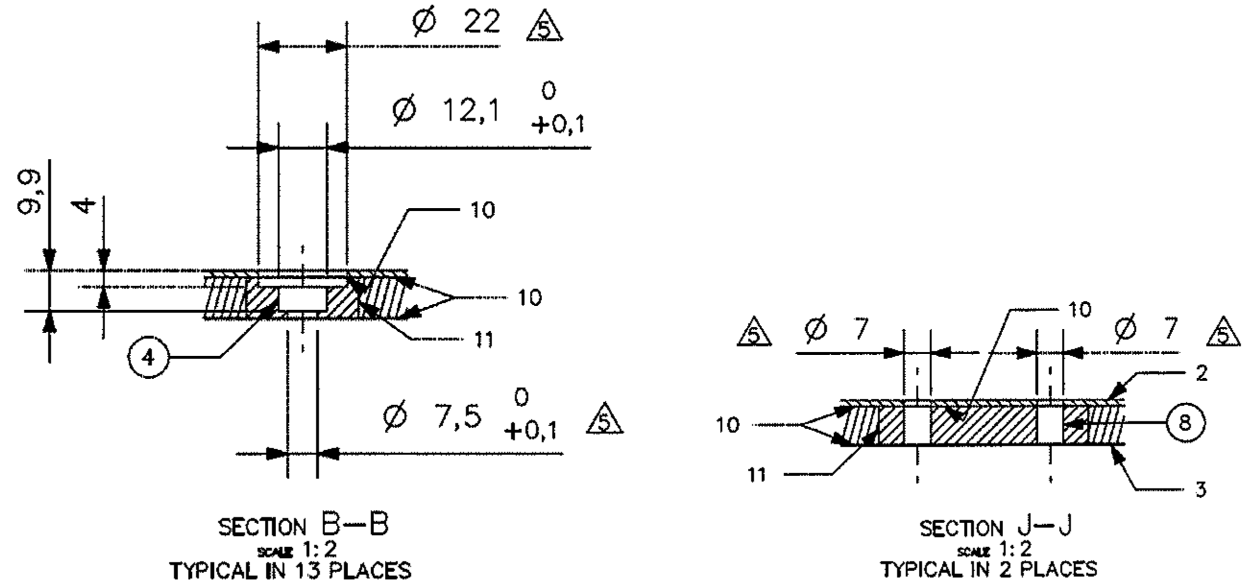


Fig. 3-12: inserts

All around the panel perimeter, a close out (mixture made of 60% Adhesive EC2216 B/A and 40% Ecchosphere IG101) 0.5mm thick, works as a Rohacell core protection.
In the following Fig. 3-13 the typical close out application:

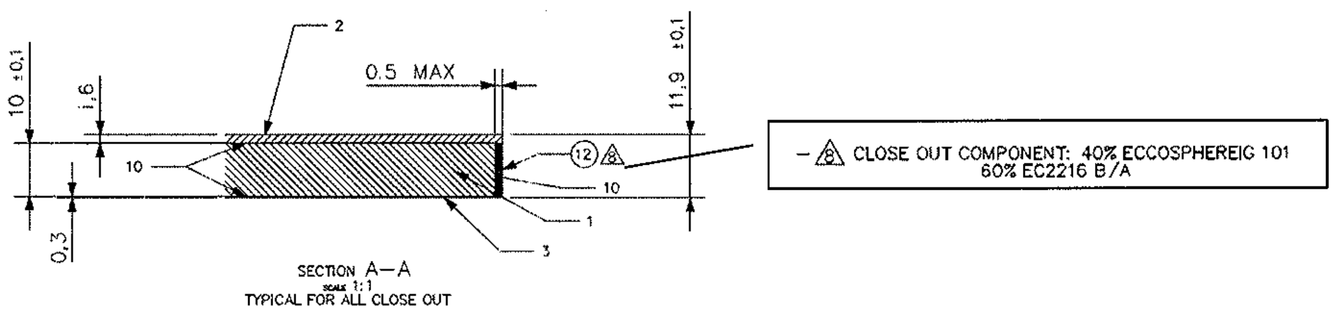


Fig. 3-13: typical close out application

The complete list of parts and material for the Zenith radiator is shown in the following table.

Part/Activity Name's	Material/Treatment	Supplier	Remarks
Outer Skin (Radiative side)	Aluminium Alloy 2024 T81 (Sheet) Spec. AMS-QQ-A-250/4 Thickness 1.6 mm	Alcoa Copper & Brass or equivalent	
Inner Skin (TRD side)	Aluminium Alloy 2024 T81 (Sheet) Spec. AMS-QQ-A-250/4 Thickness 0.3 mm	Alcoa Copper & Brass or equivalent	
Tubes	Aluminium alloy 3103 0 OD 4mm ID 3mm	Arotubi	
Bimetallic joint	4 bimetallic joints (welded at the end of each condenser tube)	Atlas	

Part/Activity Name's	Material/Treatment	Supplier	Remarks
Tubes Surface treatment	Sandblasting + scotch brite (only where is necessary)		After bimetallic welding
Outer Skin surface treatment (**before tube gluing**)	**EXTERNAL SURFACE (Radiative side)**		Primer EC 1945 B/A shall be applied within 8 hours to the anodic coating treatment
	Anodic Coating Acc. to MIL-A-8625 Type 1 Class 1 (NOT SEALED)		
	INTERNAL SURFACE (Rohacell interface)		
	Anodic Coating Acc. to MIL-A-8625 Type 1 Class 1 (NOT SEALED)	Aeroservizi	
	Sandblasting on the tube bonding pattern, to remove Anodic Coating	Aeroservizi	
Inner Skin surface treatment	**EXTERNAL SURFACE (TRD Side)**		
	Anodic Coating Acc. to MIL-A-8625 Type 1 Class 1 (NOT SEALED)		
	INTERNAL SURFACE (Rohacell interface)		
	Anodic Coating Acc. to MIL-A-8625 Type 1 Class 1 (NOT SEALED)	Aeroservizi	
Outer skin + Tube Gluing	The gluing between skin and tubes shall be done by means of Masterbond EP21TDC-2LO	Master Bond Inc.	Gluing shall be done within 24 hours to the sandblasting treatment.
Core	Rohacell 51WF Thickness 10 mm	Degussa	Row material thickness tolerance (± 0.2mm)
Core surface treatment	Backing before laminate		Heating in autoclave (temperature and time under manufacturer responsibility)
Adhesive (Skin/Rohacell)	Scotch-Weld Epoxy Adhesive 2216 B/A Gray	3M	Cold gluing
Adhesive (Insert/Rohacell)	Epoxy Paste Adhesive Hysol EA 934 NA	Loctite	Cold gluing
Inserts	Aluminium Alloy 7075 T7351 Spec. AMS-QQ-A-225/12	Alcoa Copper & Brass or Equivalent	
Inserts surface treatment	Anodic Coating Acc. to MIL-A-8625 Type 1 Class 1 (NOT SEALED)		
Close Out	Scotch-Weld Epoxy Adhesive 2216 B/A Gray	3M	60% EC2216 40% IG101
	ECCOSPHERES IG101	Emerson & Cuming	
Filled Areas (if any)	Scotch-Weld Epoxy Adhesive 2216 B/A Gray	3M	40% EC2216 60% IG101

Part/Activity Name's	Material/Treatment	Supplier	Remarks
	ECCOSPHERES IG101	Emerson & Cuming	

ZR inner surface (TRD side)	Total Planarity	2 mm
ZR Panel inner surface (TRD side)	Local Planarity (500x500mm)	1 mm
ZR Panel outer surface (Radiative side)	Total Planarity	1 5 mm
ZR Panel outer surface (Radiative side)	Local Planarity (500x500mm)	1 mm

Tab. 3-1: Zenith radiator properties, parts, materials and preferred suppliers

3.6.2 SPOKES AND BRACKETS

For each Zenith radiator, fourteen spokes plus one zeta bracket and one stiff bracket allow the right installation onto the TRD structure.

3.6.2.1 SPOKES

Spoke design consists in a GFRP rod with titanium rod ends glued at both end. The rod is made by a pre-preg pull thru GFRP, 3mm diameter
Spokes interface with the TRD structure and the Zenith radiator panel

3.6.2.2 ZETA BRACKET

Zeta bracket is a "zeta section" bracket made in GFRP. The bracket structure is made by means of the overlapping of sixteen layers of GFRP type RS 36-7781-300-38" (YLA) cured in autoclave
The bracket allows the connection of one zenith radiator panel corner with the TRD structure.
In the following figure the zeta bracket is shown.

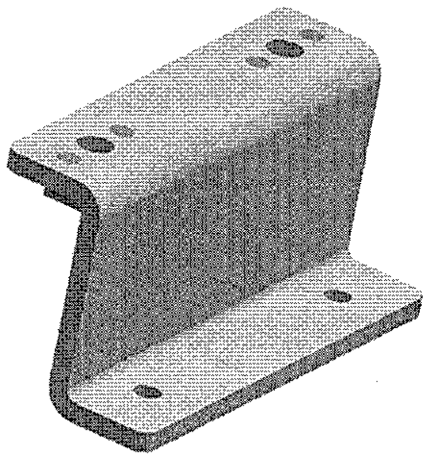


Fig. 3-14: Z-bracket

3.6.2.3 STIFF BRACKET

The stiff bracket is a numeric control machined part made in aluminium alloy 7075 T7351. The bracket works as a stiff connection between one zenith radiator panel corner and the TRD structure.
In the following figure the stiff bracket is shown.

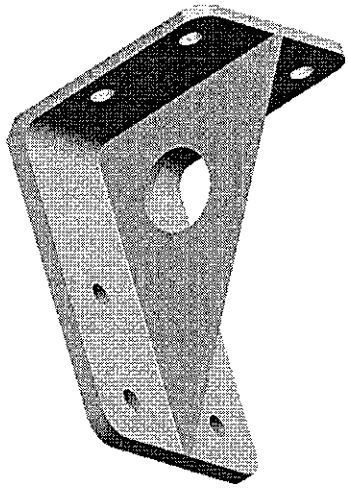


Fig 3-15: Stiff-bracket

3.6.3 RADIATOR TAPE

The outer side of the Zenith radiators shall be covered by Silver Teflon Tape, 5 mil., not embossed, perforated.
The Teflon tape shall cover as much surface as possible, with the following restrictions:

1. the tape shall be cut in patches, which shall not exceed a individual surface of 200cm2. Being the tape provided in 2" rolls, each segment shall not exceed 39cm in length.
2. adjacent patches shall be separated in any direction by a distance higher than 1mm and lower than 3mm.
3. cutouts on the tape shall be provided, in correspondence of inserts, bonding provisions and in the locations where the PT1000 sensors shall be installed. A safe distance from these locations, of 5 mm minimum and 10mm maximum, shall be left with respect to the footprint of the aforementioned items.

The Silver Teflon tape to be used is the Sheldhal – adhesive on one side, type 966 – corresponding to the following part number:

P/N 146415-002 (G401905)
Description code: VDM;G4019;CVLY;TEF;5.0 MIL;AG/INC;966;2";108' ROLL

3.6.4 PT1000

6 temperature sensors per each radiator shall be used, type PT1000. (24 sensors in total on the TCS)

Temperature sensors shall be arranged in pairs, one main and one redundant section.
A couple of sensors shall be placed close to the condenser tube inlet, a second couple close to the middle of the panel, the third couple shall measure the temperature at the condensers outlet. The location shall be the same in each of the 4 radiators.

The temperature sensors have to withstand the harsh temperature on the radiator outer face, therefore cryogenic type has to be adopted. The sensors shall be the Heraeus Type C420, whose temperature range is -196°C÷ +150°C Their tolerance is according to DIN EN 60751, class B.
The nominal resistance is 1000 Ohm at 0°C, with a thermal coefficient of 3850 ppm/K

Heraeus part number is 32 207 502; dimensions are reported below. Leads are made of AgPd.

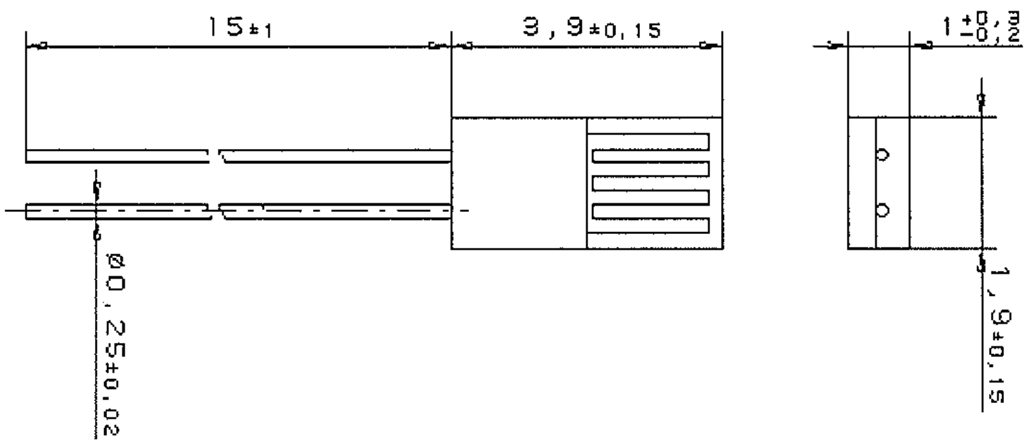


Fig 3-16: PT1000 sensor layout

The flying leads shall be soldered to appropriate cable, AWG26, capable of reaching temperatures below -125°C. The baseline for the dual core (twisted pair) cable AWG26, not shielded, is the Gore p/n SPM 20-26-C or equivalent, according to the ESA SCC 3901/018 variant 13. No compensation wire shall be used.

The wires of all the 24 PT1000 shall not differ in length by more than 1 meter, in order to minimize reading errors due to ohmic wires resistance differences. The goal is to have all the wires of the same length.

The wires on top of the radiator shall be fixed every 20 cm (6 wires bundle) or every 30 cm (2 wires bundles).

The connector of the PT1000 harness is located on the Cryocooler connectors bracket. The connector is type MIL-DTL-83513/04 Micro-D Connectors, Metal Shell Crimp, Pre-Wired, AWG 26, socket, 15 contacts, 18 inches irradiated Tefzel wires, Electronless nickel (Glenair P/N: M83513/04 B11N)

4. VERTICAL SUPPORT BEAMS

4.1 GENERAL DESCRIPTION

The Vertical Support Beams (VSB) are autoclave cured carbon fiber channels, connected to the Vacuum Case Rings by means of two aluminium supports, which serve the purpose of supporting the tubes going to the TTCS Primary and Secondary Box, the WAKE Long Cryo LHP Transport Lines and two CryoMagnetics tubes and the purpose of fastening the TTCS Primary and Secondary Box wires.
The set of tubes and wires each VSB has to carry is detailed in the following table 3.1:

VERTICAL SUPPORT BEAM POSITION	TUBES AND WIRES SUPPORTED
WAKE PORT	• Primary TTCS Box • WAKE Long CRYO LHP Transport Lines • two CryoMagnetics TUBES • wires/tubing for Primary TTCS Box
WAKE STARBOARD	• Secondary TTCS Box • wires/tubing for Secondary TTCS Box
RAM	• RAM Long CRYO LHP Transport Lines

Tab. 4-1: Vertical Support beam positions and purpose

The Vertical Support Beams are shown in the following Fig. 4-1 and Fig. 4-2:

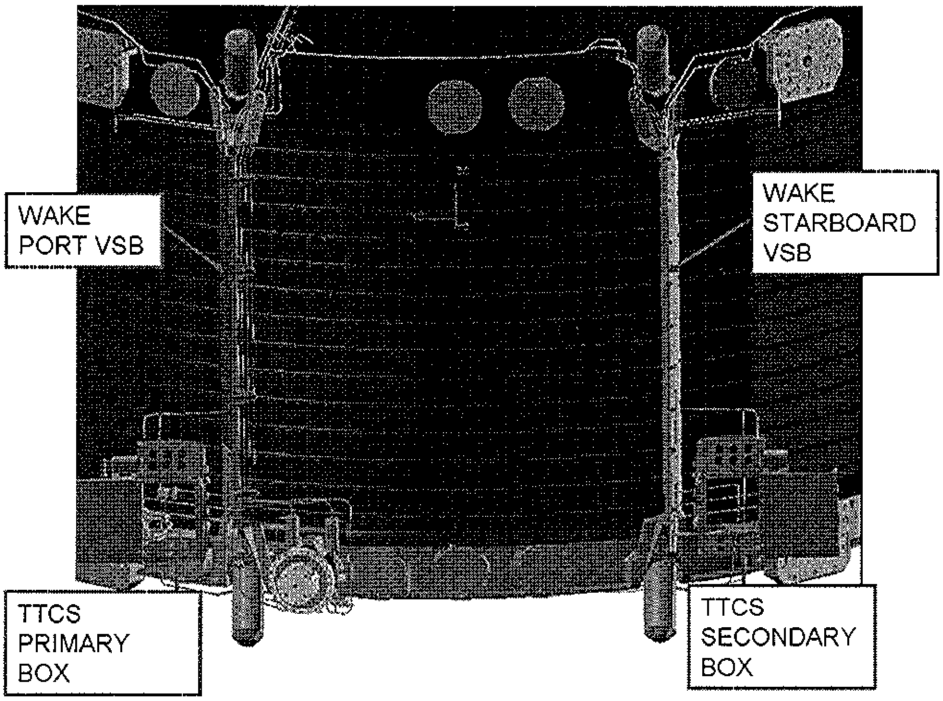


Fig. 4-1: Wake VSBs

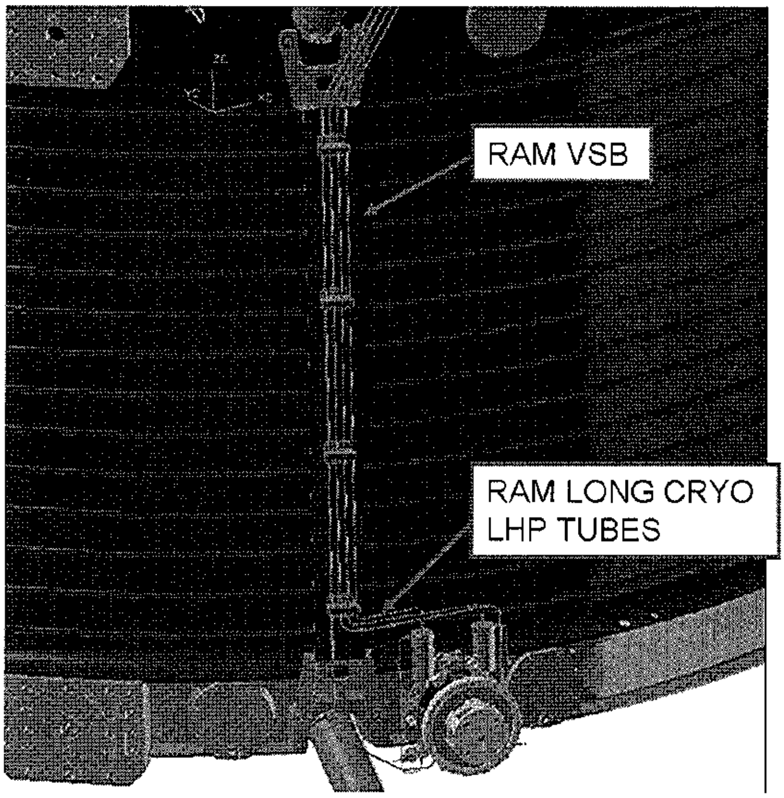


Fig 4-2: RAM VSB

The channels open section is closed with covers, which are screwed to the channel, thus giving both an increased torque resistance to the overall Vertical Support Beam assembly and an additional surface for supporting wires or tubes

The VSB's are able to withstand displacements, in the AMS02 vertical coordinate, of the Upper and Lower Vacuum Case rings through a slot placed in the Upper Supports for each VSB.

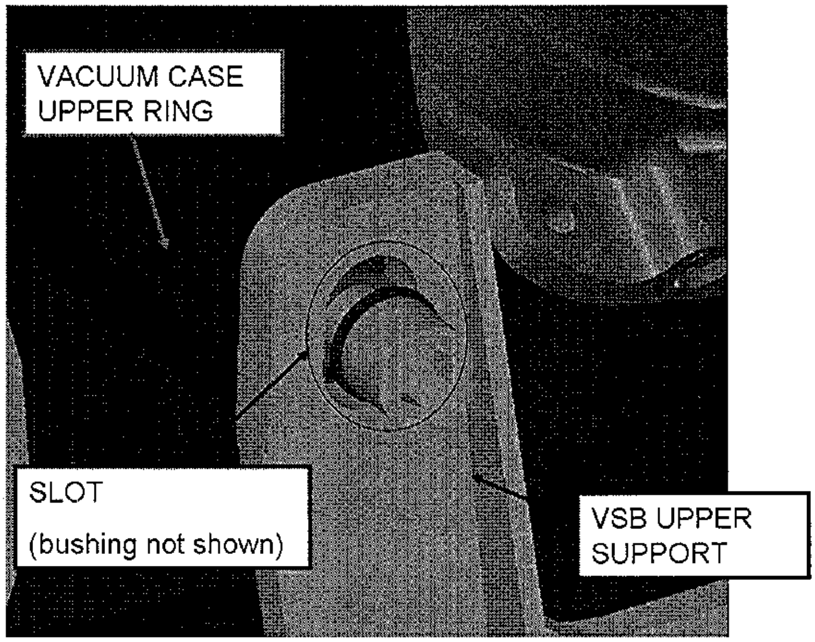


Fig. 4-3: Detail of slot for elements sliding

The materials used on the VSBs are listed in the table below.

PART NAME	MATERIAL
Channel & Covers	CARBON FIBER FABRIC PREPREG 950-1 WT650-35 3K-8H
Upper & Lower Supports	Aluminium Alloy 7075 T7351 SPEC. QQ-A-250/12
Bushings	Steel 15-5PH H1025 AMS5659 plus KETRON PEEK 1000 washer
Internal Supports, Lateral Brackets and Frontal Brackets	KETRON PEEK 1000 SPEC. MIL-P-46183

Tab. 4-2: Vertical Support beam materials

4.2 WAKE PORT VERTICAL SUPPORT BEAM

The channel open section allows the TTCS Primary Box tubes to be placed by using four Internal Supports, while the WAKE Long Cryo LHP Transport Lines and the CryoMagnetics tubes are connected to the channel with four Lateral Brackets. The WAKE PORT Vertical Support Beam is rotated clock wise on its longitudinal dimension by 50 degrees pointing to the PORT and to the TTCS Primary Box, as shown in the next figure.

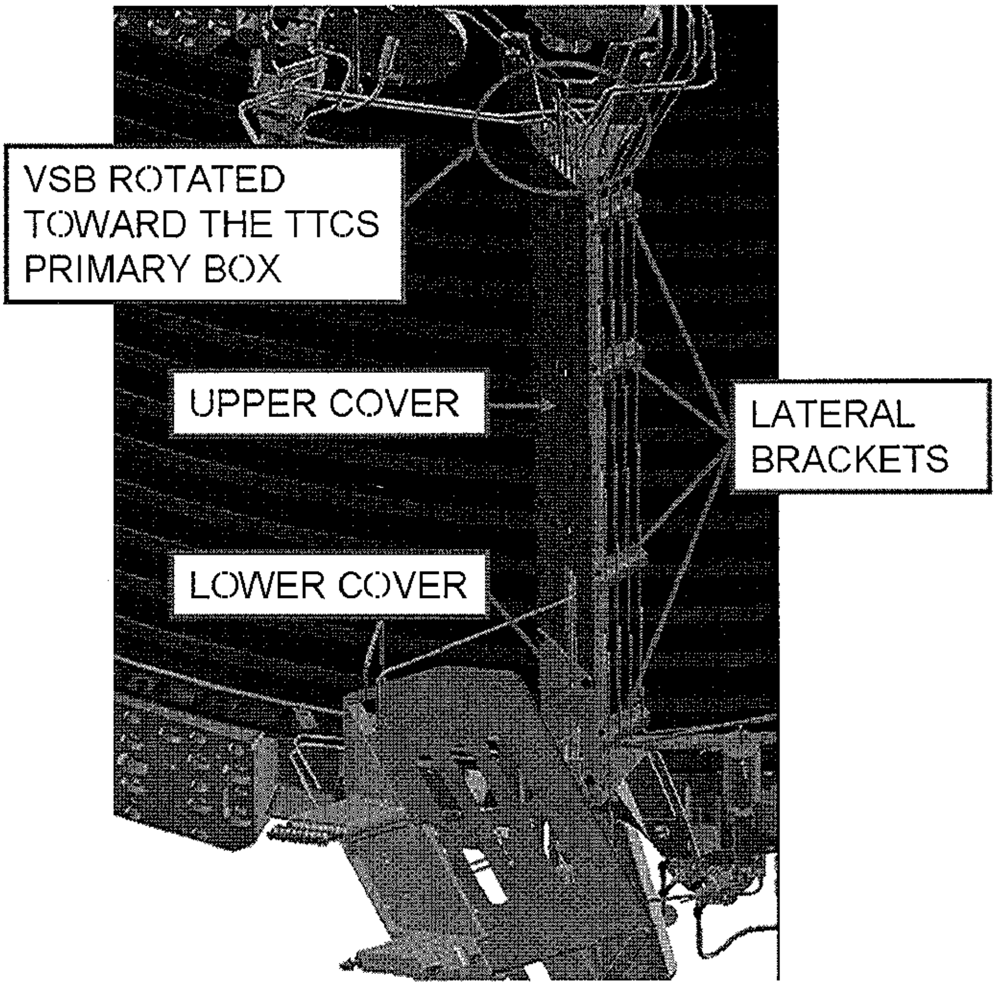


Fig. 4-4: Wake-Port VSB layout

The WAKE PORT VSB components are shown in the following Fig. 4-5:

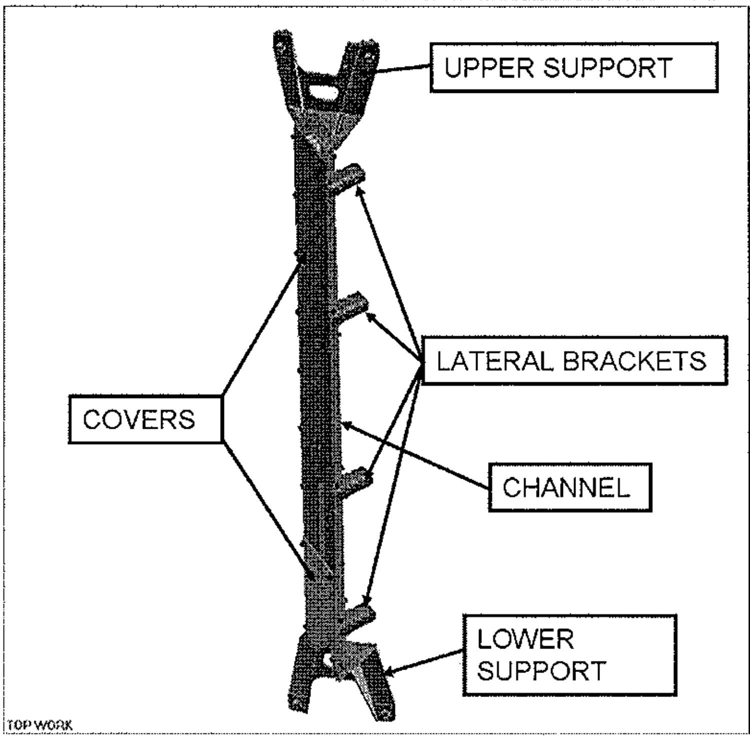


Fig. 4-5: Wake-Port VSB components

The Primary TTCS Box tubes will be fixed to the covers, which have been provided with slots. Additional slots have also been added to the covers in order to allow the TTCS tubes to exit the channel section at specified locations as shown in the following figure:

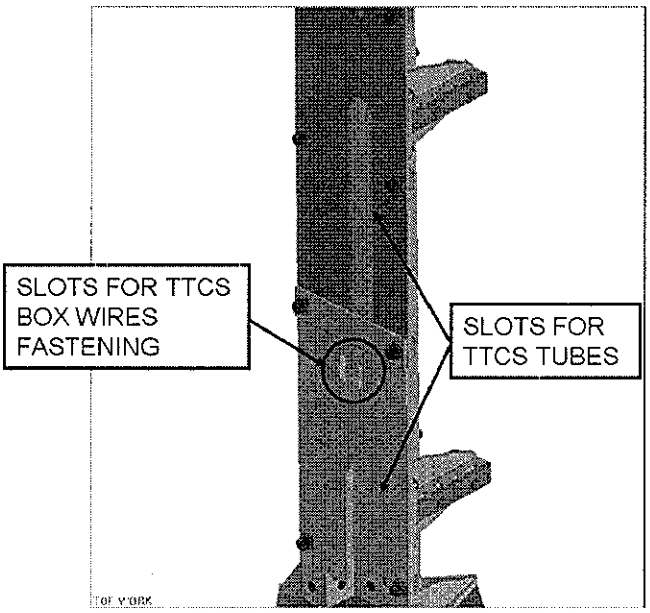


Fig 4-6: Wake-Port VSB slots for tubing

The single parts of the WAKE PORT VSB are described in the following sections.

4.2.1 UPPER AND LOWER SUPPORTS

The Upper and Lower Supports, which are numeric control machined parts made of aluminium alloy 7075 T7351, are the link between the channel and the Vacuum Case Upper and Lower Rings.

4.2.2 CHANNEL

The channel is the part of the Vertical Support Beam to which the TTCS tubes, LHP Transport Lines and the CryoMagnetics tubes are connected by using brackets and/or spacers placed in the inside or on the walls of its opened section whose dimensions are shown in the following figure

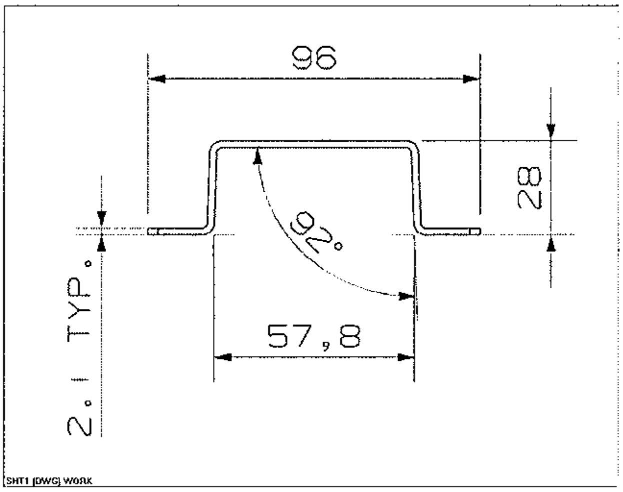


Fig 4-7: Channel cross section

The channel is made of six layers of fabric prepreg carbon fiber.

4.2.3 BUSHINGS

The Upper Supports and the Lower Supports are provided with two different types of bushings, both made of Steel 15-5PH H1025, in order to guarantee the proper interface between the supports and the Upper and Lower Vacuum Case Rings. The Upper Bushings are positioned in the slots of the Upper Support facing the Vacuum Case Upper Ring. The Lower Bushings position is instead at the interface between the Lower Support and the Vacuum Case Lower Ring with no TEFLON rings. The Bushings are detailed in the following figures:

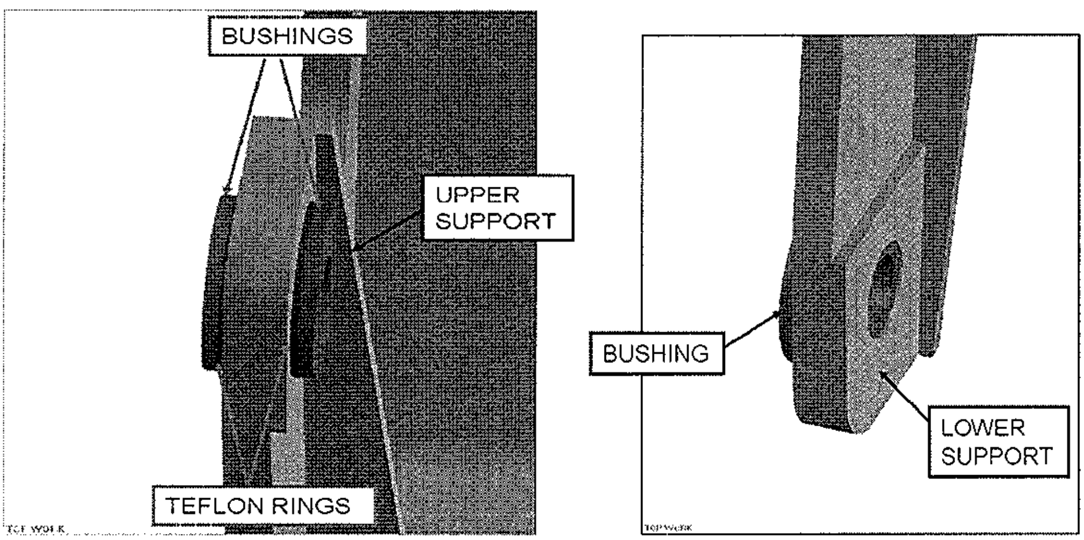


Fig 4-8: VSB bushings

4.2.4 INTERNAL SUPPORTS

The TTCS primary box tubes are placed inside the WAKE PORT Vertical Support Beams channel open section using four Internal Supports each made of three different KETRON PEEK 1000 parts: a Bottom Support, a Tube Spacer and a Top Support.

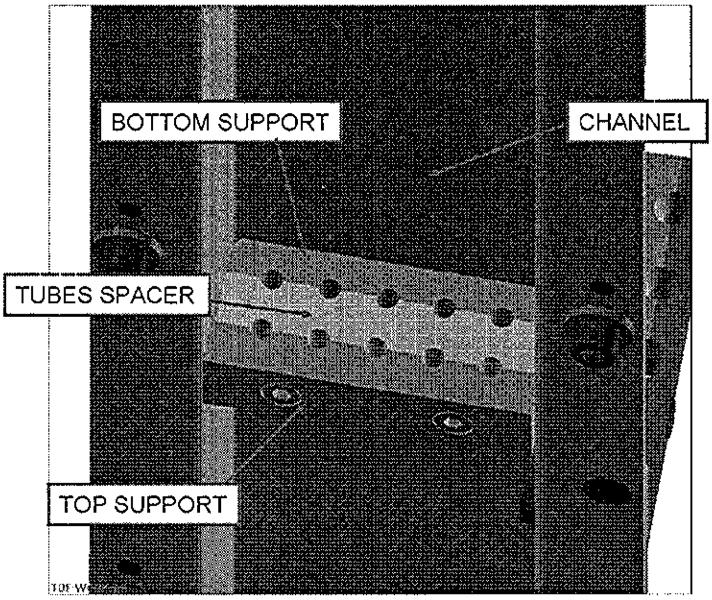


Fig. 4-9: VSB internal supports

4.2.5 LATERAL BRACKETS

The Lateral Brackets are made of a Main Support, a Top Clamp and a Rear Clamp, each made of KETRON PEEK 1000 and connect the WAKE Long Cryo LHP Transport Lines and the CryoMagnetics tubes to the channel, as detailed in the following figure:

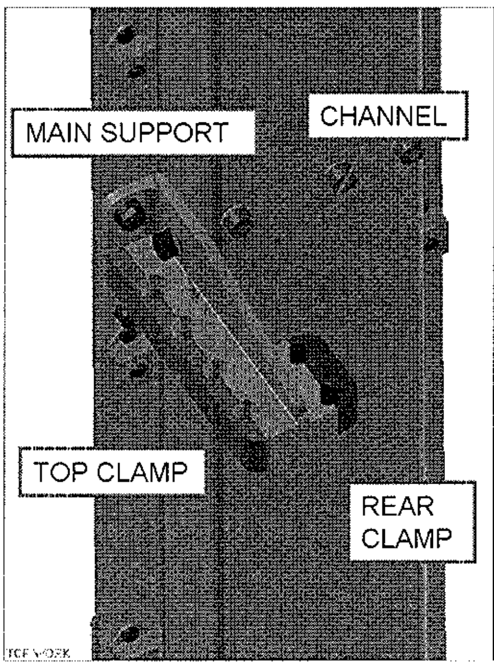


Fig. 4-10: VSB Loop heat pipes transport lines supports

4.2.6 UPPER AND LOWER COVERS

The WAKE PORT VSB channel cover is made of two different parts: an Upper Cover and a Lower Cover, both made of six layers of fabric prepreg carbon fiber, in order to facilitate the TTCS tubes positioning inside the channel. The Upper and Lower Covers are shown in the Fig. 4-4

4.3 WAKE STARBOARD VERTICAL SUPPORT BEAM

The WAKE STARBOARD VSB has to support only the TTCS Secondary Box tubes and it is therefore rotated counter clockwise by 50 degrees on its longitudinal dimension pointing to the STARBOARD direction. The Upper and Lower Supports and the Covers are then equal to those used on the WAKE PORT VSB but mirrored with respect to the Y-Z plane in the AMS02 Global Coordinate System. The Channel, the Bushings and the Internal Supports are instead those used on the WAKE PORT VSB.
Since the WAKE STARBOARD Vertical Support Beam only has to carry the TTCS Secondary Box tubes and the TTCS Secondary Box wires on its cover and no other tubes, it has no Lateral Brackets. The WAKE STARBOARD VSB is shown in Fig. 4-1.

4.4 RAM VERTICAL SUPPORT BEAM

It carries only the Long RAM CRYO LHP tubes, therefore it is not rotated on its axis but it is pointing outward in the radial direction.
The Channel and the Upper and Lower Bushings are those used on the WAKE PORT and WAKE STARBOARD Vertical Support Beams while the Upper and Lower Supports are similar to those used on the two above mentioned VSBs except for giving no rotation to the channel. See Fig. 3-3.
The LONG RAM CRYO LHP Transport Lines are supported by the RAM VSB by using four Frontal Brackets screwed to the Cover, which, for this VSB, is a single part made of a six layers carbon fiber fabric prepreg.

4.4.1 FRONTAL BRACKETS

The Frontal Brackets are "KETRON PEEK 1000" machined parts composed by a Main Support fixed to the Cover and a Top Clamp as detailed in the next figure:

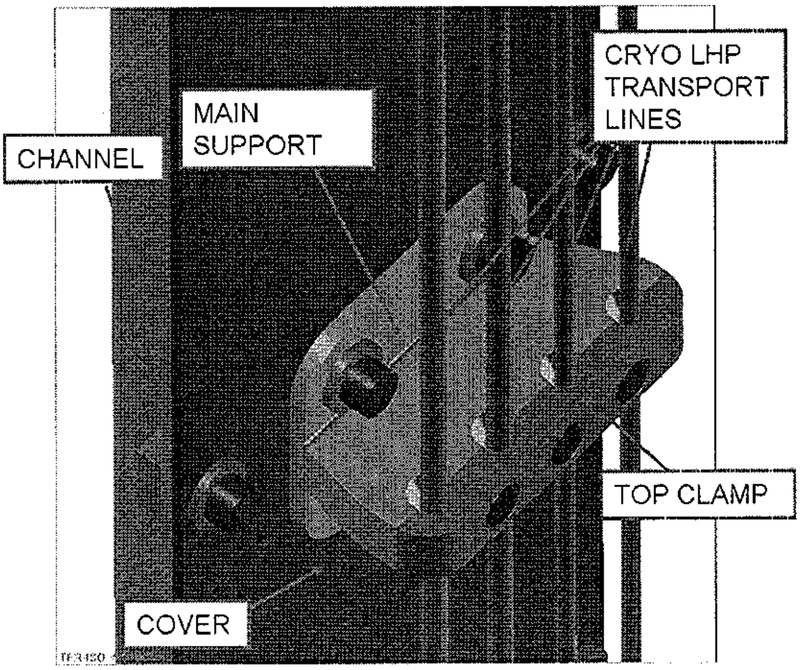


Fig. 4-11: VSB Loop heat pipes transport lines supports

ANNEX 1. LHP DRAWINGS